ARKIV FÖR FYSIK Band 13 nr 41

Communicated 9 April 1958 by The Svedberg and Arne Westgren

A flexible 20-channel time-delay and pulse-height analyser. Equipment for pulsed bombardment study of short-lived nuclei in a cyclotron

By P. A. Tove

With 5 figures and 17 diagrams in the text

ABSTRACT

A multi-channel pulse analyser is described which is suitable for time-delay analysis of events in the range from 1 microsecond to minutes or more. Applications are lifetime measurements on isomers in this region, and with auxiliary equipment, pulsed bombardment studies of short-lived nuclei produced in an accelerator. The time sorting is done by count channels which are successively opened and shut. The analyser is easily converted to a pulse-height analyser.

Introduction

The term "time-delay analyser" is used for an electronic device which allows determination of the distribution in time of pulses, relative to a reference event. The pulses are sorted in some kind of memory, such as scalers, according to their time interval from the reference instant. The device has gained large application in nuclear physics experiments. One use is for the measurement of radioactive decays. Another is for the determination of the velocity or energy distribution of particles by measurements of their travel time over a distance.

This work describes a 20-channel time analyser which has been used for measurements on the decay of nuclei with lifetimes above 1 microsecond. The fundamental part of the analyser, performing the time sorting mechanism, consists of 20 count channels, which are successively opened and shut in turn by control pulses. Each channel consists of a scaler with a gate circuit, which is controlled by a bistable multivibrator, commonly called "flip-flop".

1. In the first application the analyser has been used for rather slow decay measurements in the millisecond range and above. The main use has been in investigations of short-lived nuclei produced by short bombardments in the beam of a cyclotron [1, 2]. Devices which allow automatically repeated irradiations for gaining better information about weak activities will also be described.

2. Another application has been for measurements on the decay of isomeric states which are fed from longer-lived parents [3]. The feeding transition is used as the time reference event and the subsequent decay of the isomer is measured by the time analyser. The range of half-lives that can be measured is from 1 microsecond up to the millisecond region.

3. A further use of the fundamental channel system has been as a multi-channel pulse-height analyser of a new type. In this case the rapid sequence of opening and closing the channels is started by the pulse whose height is to be analysed. The pulse is also transformed into another whose length is proportional to the height of the incoming pulse. The transformed pulse is differentiated and the trailing edge passes into the channel which is open at that time. The number of the channel which is hit is thus a measure of the height of the incoming pulse.

4. A special application of the device as a pulse-height analyser is the use, together with the automatic-repetitive irradiation circuits, for pulse-height analysis during an interval at a chosen time in the measurement period after the pulsed bombardments.

Description of the circuitry

1. *Arrangement for pulsed-bombardment study of short-lived nuclei in a cyclotron*

In the study of nuclear spectroscopy the nuclide under investigation most often is rather long-lived, or is preceded by a long-lived parent, which is produced in a bombardment process in an accelerator. The half-life has to be sufficiently long to allow chemical separations and mounting and measurement in a spectrometer. To study short-lived nuclei produced directly in a nuclear reaction, other methods have to be used. The present equipment allows measurements on short-lived activities produced by an internal synchrocyclotron beam. The radiation from the activity is detected in scintillation crystals placed close to the target. Light guides feed the light pulses to photomultipliers outside the cyclotron magnetic field. The internal target is irradiated during a short time interval, of the order of the half-life of the activity under investigation. After the beam has been shut off by pulsing the cyclotron oscillator, the detector starts detecting radiation. In order to determine the time distribution of the detector pulses, the latter are fed to the time analyser. The pulses stored in a certain channel thus measure the radiation from the target at a certain time after the beam has been shut off. The time interval a channel is open is controlled by a pulse generator; it can be the same for all channels or it can be increased 2, 4 or 8 times for any desired channels. After this "count period", which is of the order of a few half-lives, a recovery period begins, which allows longer-lived activities produced during the irradiation to decay. A new period of bombardment then follows and the whole cycle is repeated automatically. By thus adding the pulses from many repetitions of the cycle one can gain information about nuclei of fairly small production cross sections. Typical experiments involve 5 to 1000 repetition cycles. The range of half-lives which can be measured extends down to the millisecond region. To discriminate against background in the cyclotron, two scintillation detectors can be used in a coincidence circuit with a resolving time of 10^{-8} sec.

Before passing to a discussion of the circuitry, a description will be made of the mechanical build-up and of the nomenclature used in the diagrams. A rather detailed function description will be given in order to facilitate reading of the diagrams. The electronic circuits are built on subchassis which are mounted vertically in a rack, Fig. 1, to the left, to form a cooling chimney. The electronic tubes are placed inwards in the chimney and the components outwards for easy access. The subchassis form several "floors". In between these are "bus bars" going around the chimney. These bars supply the high voltages, -150, $+280$ and $+300$ V stabilized, and the filament

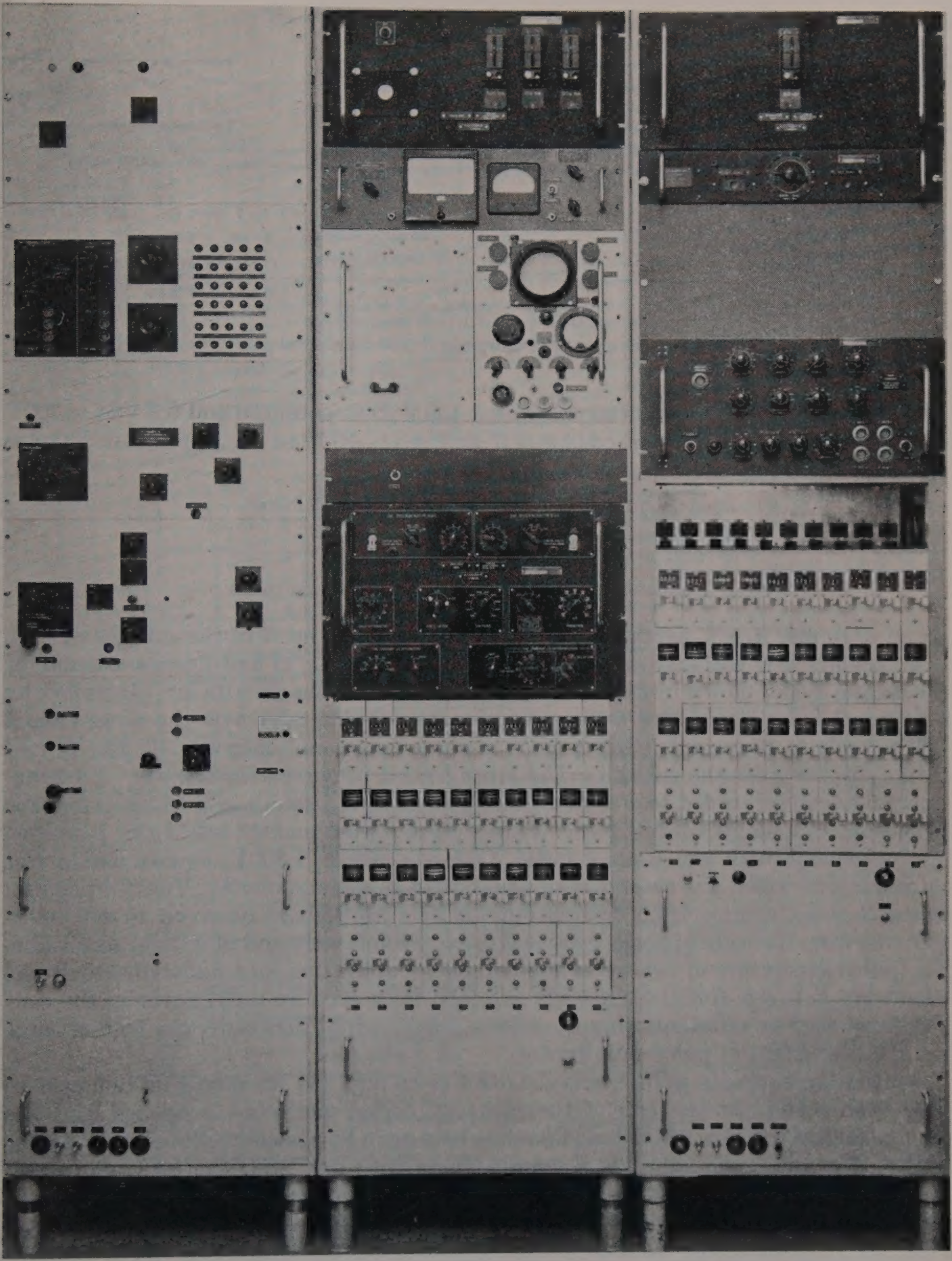


Fig. 1. The time-delay and pulse-height analyser with associated equipment. In the left rack are the analyser circuits, while the scalers are in the lower parts of the other two. Above these are the control pulse generator, an amplifier with a single-channel discriminator and an oscilloscope for checking the waveforms.

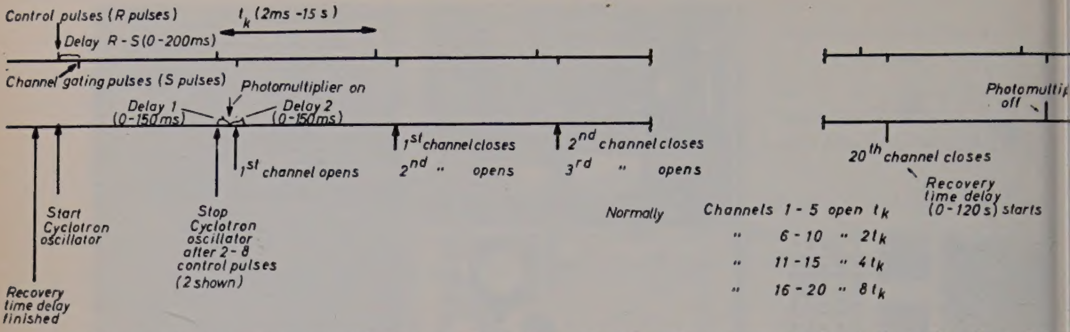


Fig. 2. Time sequence of different events in the pulsed bombardment study of short-lived nuclei.

voltages, 6.3 V at earth potential, 6.3 V at +150 V D.C. potential and 6.3 V at +300V D.C. The subchassis are marked *A1–A17* and *AG1–AG20* in the functional diagram *A0*. Some symbols used in the diagrams are

C	capacitance	*P*	potentiometer
G	indication glow lamp	*R*	resistor
K	relay	*S*	switch
L	inductance	*V*	electronic tubes

As an example, $A3V7_1$ means the grid (first pin) of tube no. 7 in the subschassis *A3*.

To achieve best stability and flexibility for a wide range of half-lives, a scheme for the timing cycle, shown in Fig. 2, was chosen, in which the circuits are controlled by a "control pulse" generator with pulse separation adjustable over the range from 2 milliseconds to 15 seconds. Reference is made to functional diagram *A0*, Fig. 3, and to the diagrams for the subunits. The arrangement of current interest is "*TA* function". The pulses are fed to a second pulse generator in subunit *A6*, which gets three pulses out of a single control pulse. Two of these, subsequently called the *R* pulses, are coincident with the control pulse. One is positive +30 V, square and a few microseconds wide. The second is similar but of negative polarity. The third pulse, called *S* pulse, coming from two outputs, is delayed a short time (up to 200 milliseconds) from the control pulse, is several microseconds wide and of +75 V amplitude. The pulse generators in *A6* are of the cathode-coupled one-shot multivibrator type. The delay between *R* and *S* pulses is obtained from such an univibrator in the conventional way by differentiating the square wave output and using the trailing edge for triggering the *S* pulse univibrator.

During the recovery period, relay *A10K1* is on and the R_+ pulses do not pass to gate tube *A4V4*. At the end of the recovery period the relay is opened and the R_+ pulses pass the gate which is at this time held open by the controlling flip-flop tube *A4V2*. The gate tube *A4V4* is a double-triode with one grid, the controlling grid $A4V4_6$, kept at +230 V in the closed condition and ca. 70 V in the open condition. As the bias on the other grid $A4V4_5$ is 55 V, this means that in the open state a 30 V pulse on $V4_5$ causes the current to shift between the two triodes, giving a positive output on the $A4V4_1$ anode. Opening of the gate does not give an output pulse because of the grid-catching diode *V9b*.

The first R_+ pulses coming after the relay has been opened passes to and triggers a pulse generator in subunit *A11* which delivers a large pulse, suitable for triggering

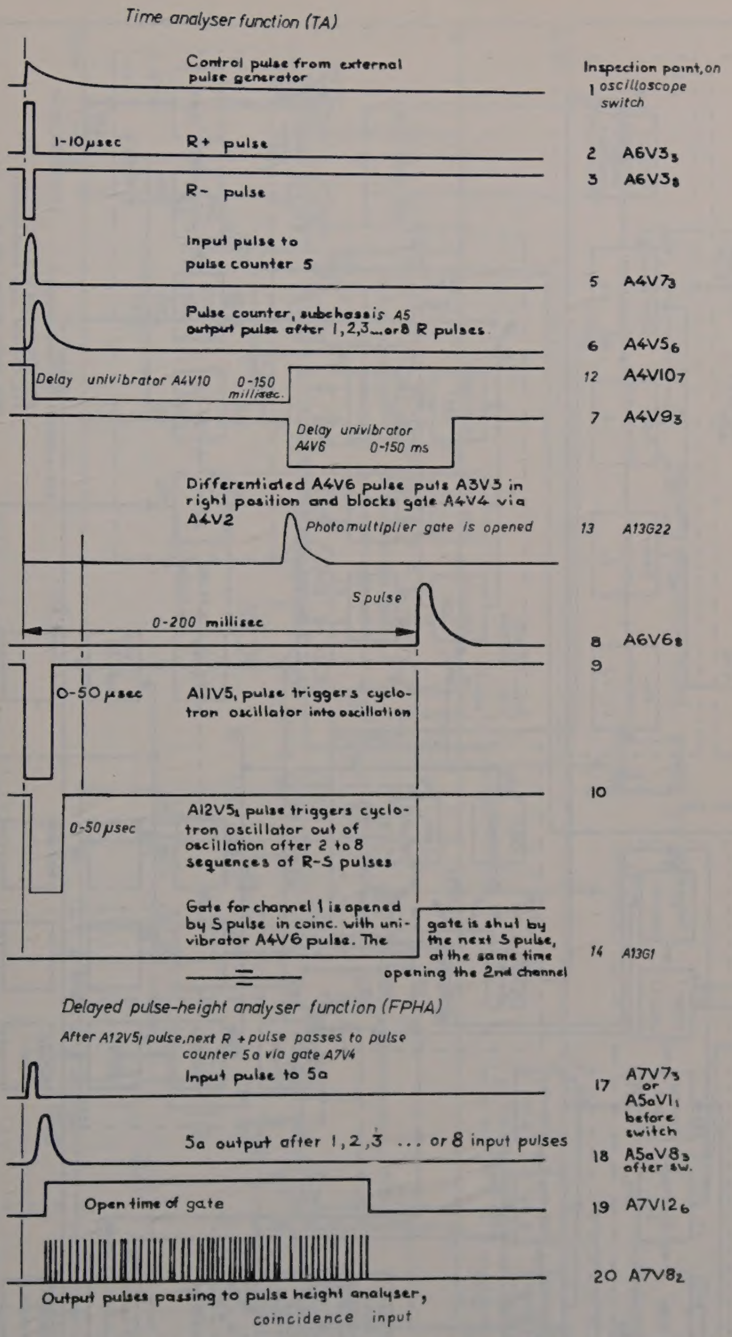
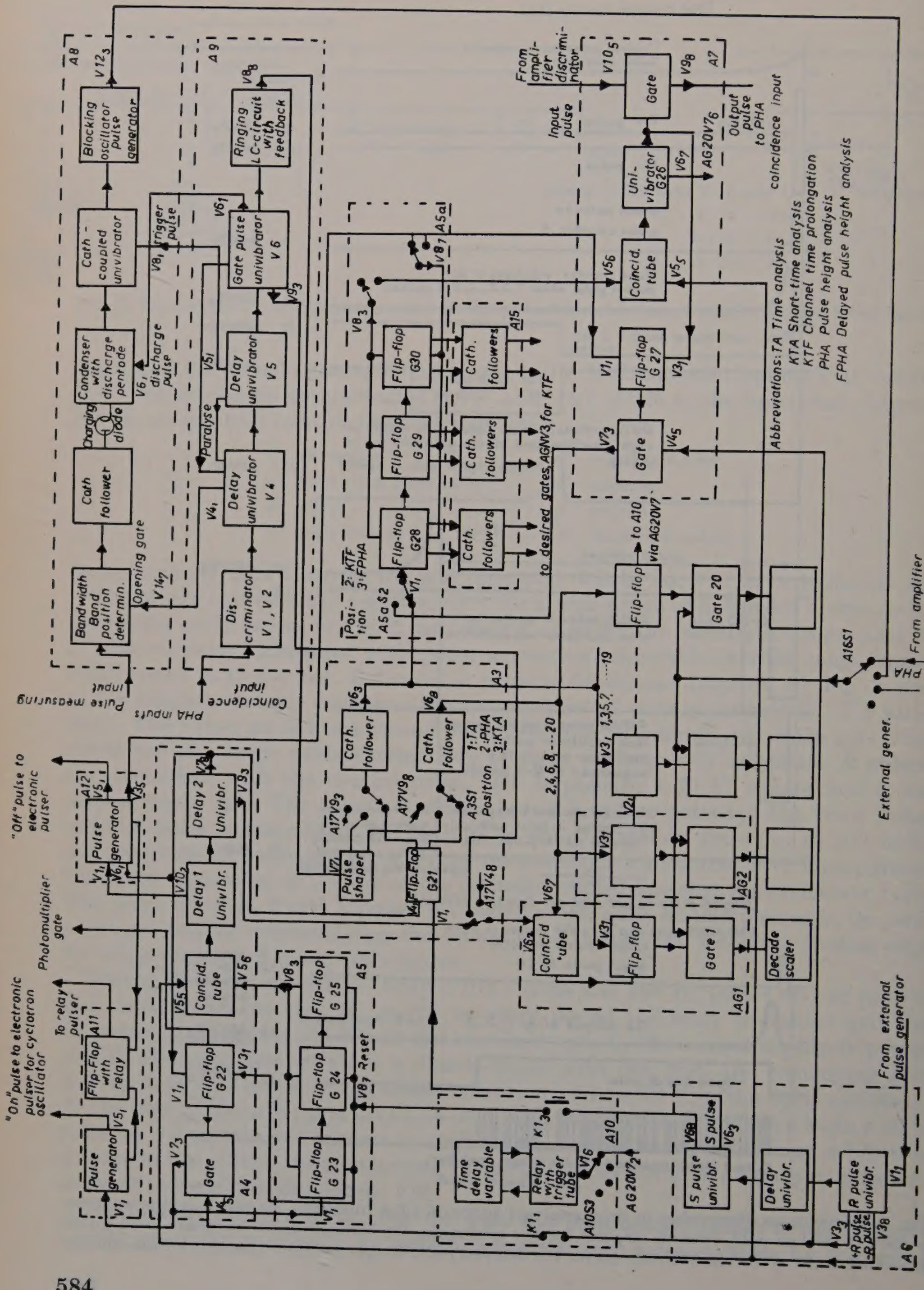
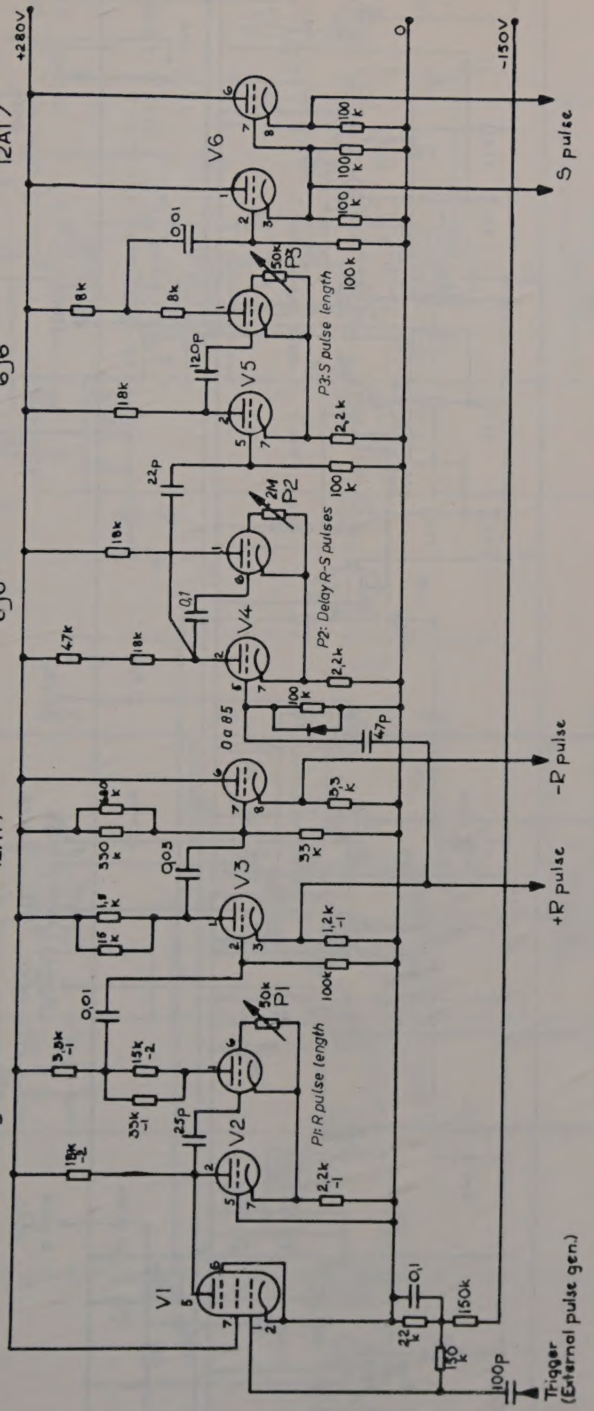
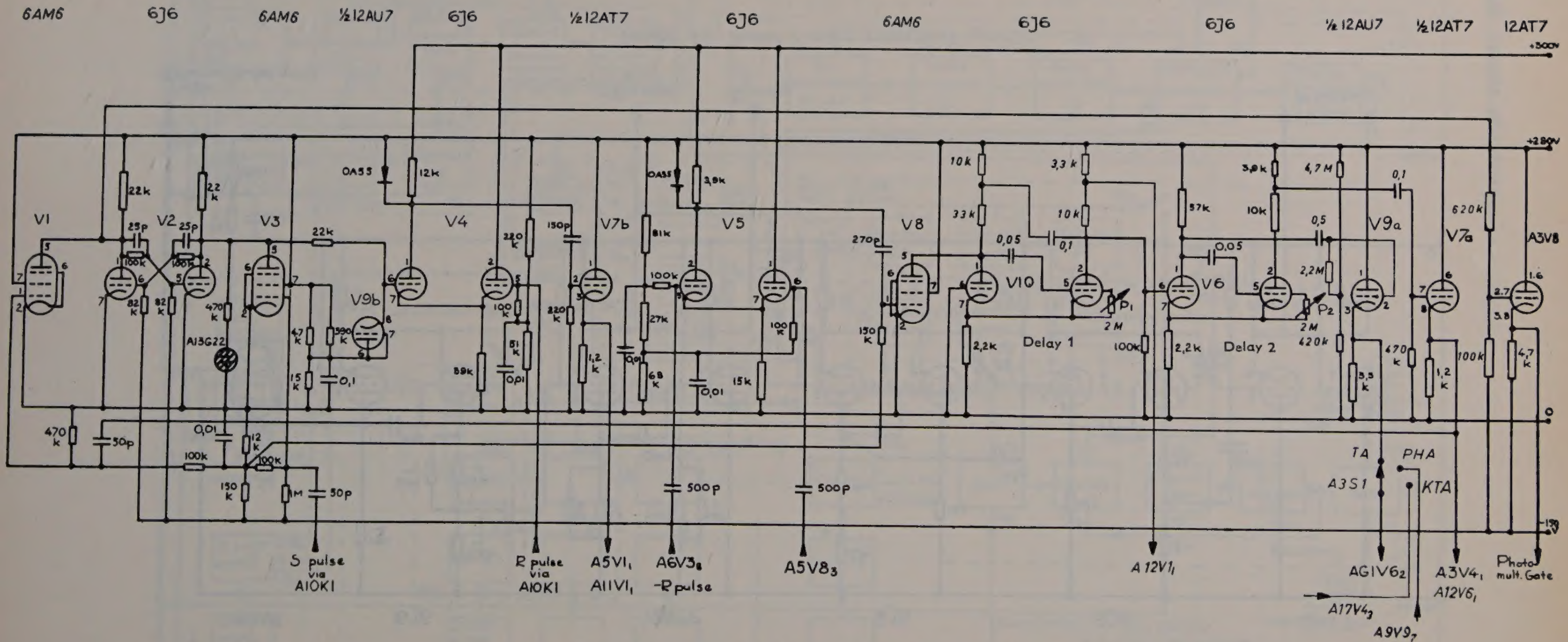

Time analyser function (TA)
Control pulse from external pulse generator
Inspection point, on oscilloscope switch
1
1-10 μsec
R+ pulse
2 A6V3₃
3 A6V3₈
R- pulse
Input pulse to pulse counter 5
5 A4V7₃
Pulse counter, subchassis A5 output pulse after 1,2,3...or 8 R pulses
6 A4V5₆
Delay univibrator A4V10 0-150 millisec.
12 A4V10₇
7 A4V9₃
Delay univibrator A4V6 0-150 ms
Differentiated A4V6 pulse puts A3V3 in right position and blocks gate A4V4 via A4V2
Photomultiplier gate is opened
13 A13G22
S pulse
0-200 millisec
8 A6V6₈
9
0-50 μsec
A11V5, pulse triggers cyclotron oscillator into oscillation
10
0-50 μsec
A12V5₁ pulse triggers cyclotron oscillator out of oscillation after 2 to 8 sequences of R-S pulses
Gate for channel 1 is opened by S pulse in coinc. with univibrator A4V6 pulse. The
gate is shut by the next S pulse, at the same time opening the 2nd channel
14 A13G1
Delayed pulse-height analyser function (FPHA)
After A12V5₁ pulse, next R + pulse passes to pulse counter 5a via gate A7V4
Input pulse to 5a
17 A7V7₃ or A5aV1₁ before switch
5a output after 1,2,3 ... or 8 input pulses
18 A5aV8₃ after sw.
Open time of gate
19 A7V12₆
20 A7V8₂
Output pulses passing to pulse height analyser, coincidence input

Fig. 3. Waveforms observable in time analyser function (*TA* function). In this case the analyser is used, together with control circuits for the cyclotron, for measurements on short-lived nuclei produced in the cyclotron. Waveforms for the delayed pulse-height analyser function are also shown.

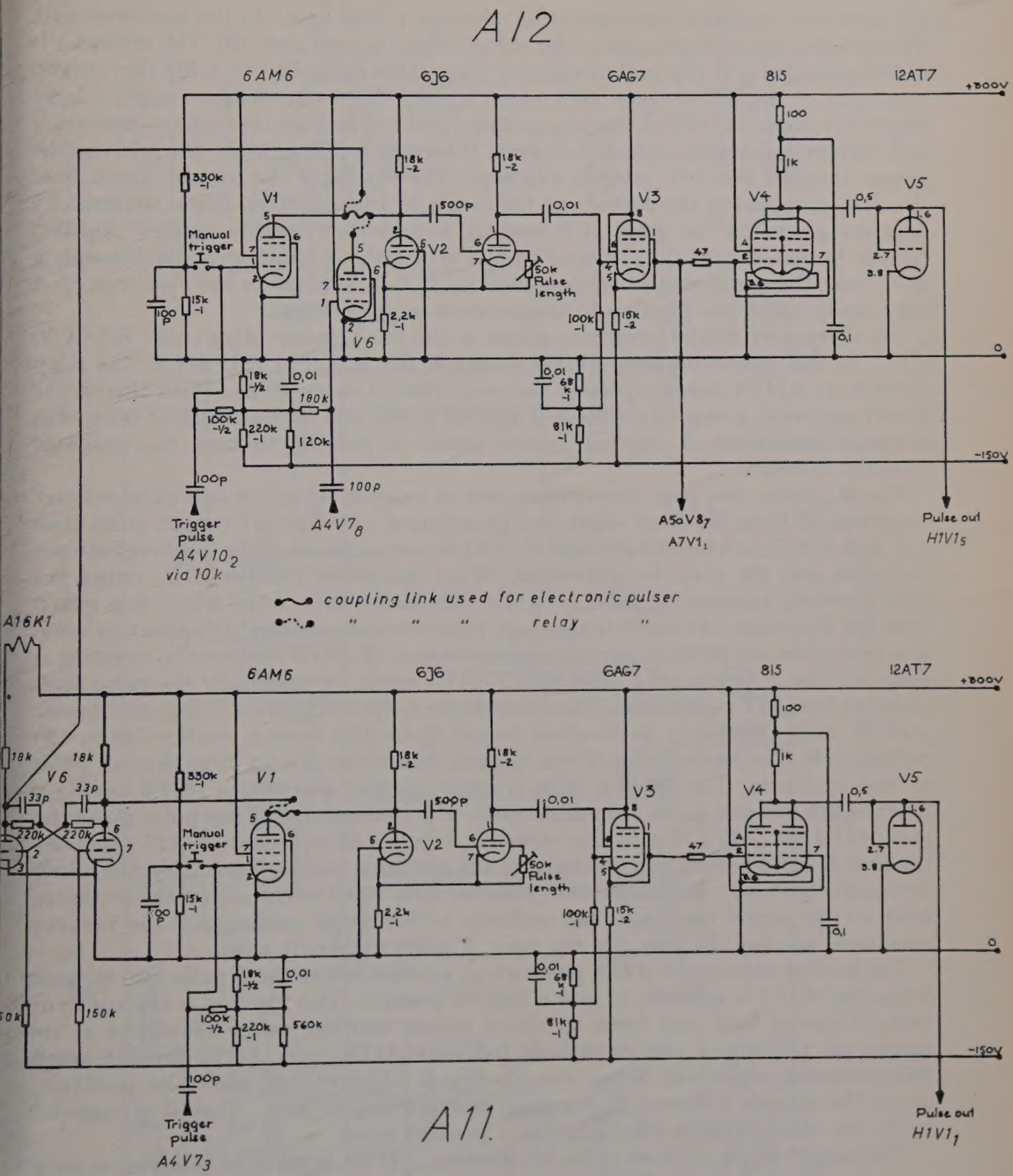

A8
Bandwidth Band position determin.
Cath follower
Condenser with discharge pentode
Charging diode
Cath - coupled univibrator
Blocking oscillator pulse generator
V12₃
Opening gate
V14₇
V6₁ discharge pulse
V8₁ trigger pulse
V6₁
Pulse measuring input
A9
Dis-criminator V1, V2
Delay univibrator V4
Delay univibrator V5
Gate pulse univibrator V6
Ringing LC-circuit with feedback
V8₈
V4₁
V5₁
V9₃
Paralyse
Coincidence input
PHA inputs
"Off" pulse to electronic pulser
A12
Pulse generator
V5₁
V3₅
V1₁
V6₁
Photomultiplier gate
"On" pulse to electronic pulser for cyclotron oscillator
To relay pulser
A11
Flip-Flop with relay
Pulse generator
V5₁
V1₁
Delay 1 Univibr.
Delay 2 Univibr.
V10₂
V3₃
V9₃
Coincid. tube
V5₅
V5₆
Flip-flop G22
V1₁
V3₁
Gate
V7₃
A4
K5
Flip-flop G23
Flip-flop G24
Flip-flop G25
V8₃
V8₇
V1₁
Reset
A5
A17V9₃
Pulse shaper
V7₁
Cath. follower
V6₃
A17V9₈
Cath. follower
V6₈
Flip-flop G21
A17V4₈
V4₁
V1₁
A3S1 Position
1:TA
2:PHA
3:KTA
A3
Posi-tion
2: KTF
3: FPHA
A5a S2
Flip-flop G28
Flip-flop G29
Flip-flop G30
V1₁
V8₃
V8₇
A5a1
Cath. followers
Cath. followers
Cath. followers
A15
to desired gates, AGNV3 for KTF
From ampli-fier discrimi-nator
Input pulse
V10₅
Gate
V9₈
A7
Output pulse to PHA
Uni-vibrator G26
V6₇
AG20V7₆
Coincid. tube
V5₆
V5₅
Flip-flop G 27
V1₁
V3₁
Gate
V7₃
V4₅
coincidence input
Flip-flop
to A10 via AG20V7
Gate 20
2,4,6,8,...20
1,3,5,7,...19
V3₁
V2
V3₁
V3₁
V6₇
V6₂
Coincid tube
Flip-flop
Gate 1
Decade scaler
AG1
AG2
A18S1
PHA
TA
From amplifier
External gener.
Abbreviations: TA Time analysis
KTA Short-time analysis
KTF Channel time prolongation
PHA Pulse height analysis
FPHA Delayed pulse height analysis
Time delay variable
Relay with trigger tube
K1₁
K1₃
V1₆
A10
A10S3
AG20V7₂
S pulse univibr.
V6₈
S pulse
V6₃
Delay univibr.
R pulse univibr.
V1₁
+R pulse
-R pulse
V3₂
V3₈
A6
From external pulse generator



Diagr. A6. R and S pulse generators.



Diagr. *A4.* Gate and delay unit for *TA* function.



Diagr. *A11* and *A12*. Pulse generators for cyclotron pulser.

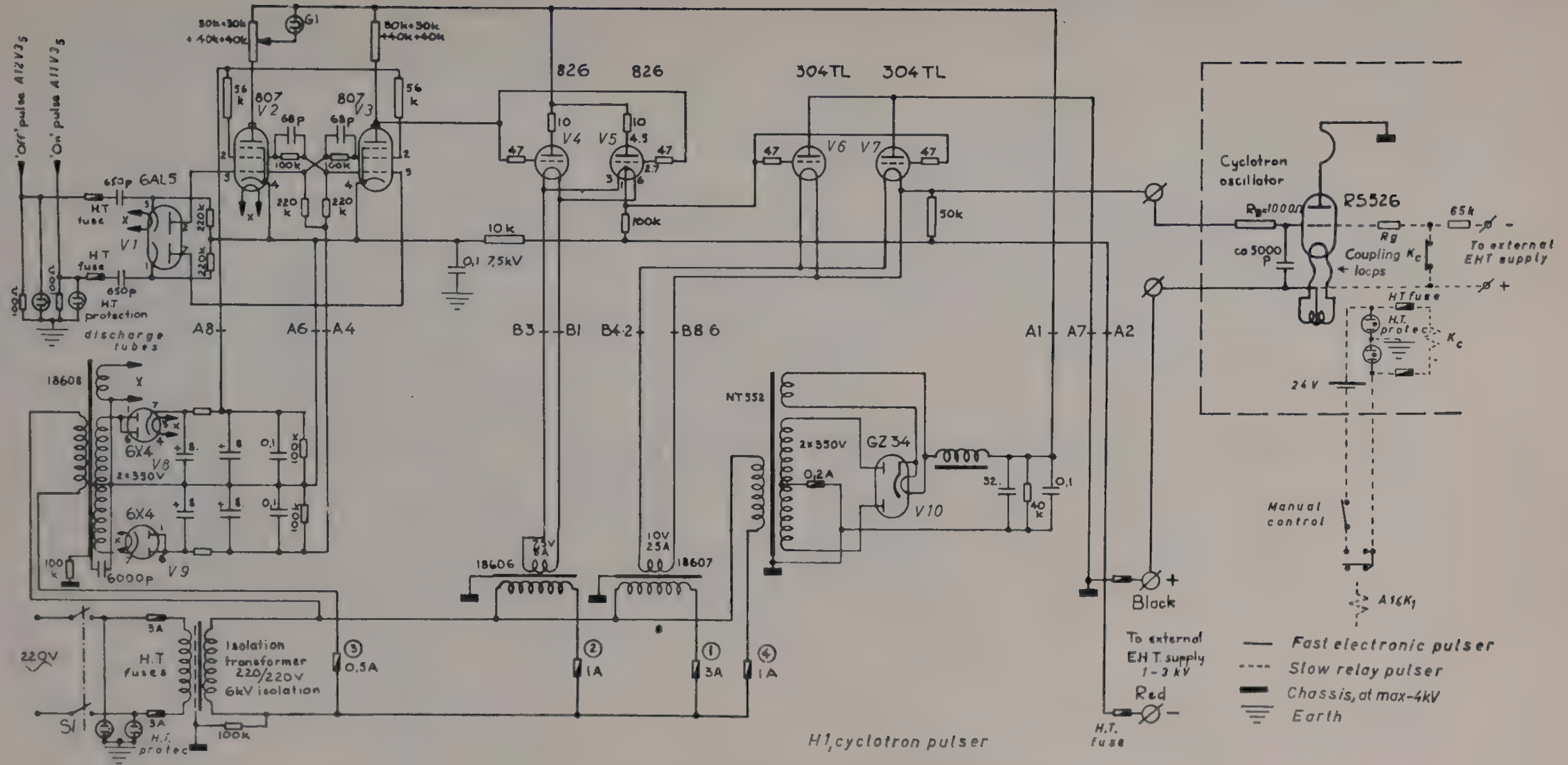
the cyclotron oscillator into oscillation, through a long cable to the cyclotron hall. This is when the electronic pulser for the oscillator is used (see *A0*). The oscillator is of the grounded-grid (for radio frequency) type. It is controlled by a flip-flop circuit, consisting of two 807's (diagr. *H1*), which to shut down the oscillator apply a large negative voltage, ca. 1 kV, across the oscillator grid and cathode through two insulating and current-amplifying cathode-followers. When the oscillator runs, the grid current passes through the last cathode-followers. The chassis of the control circuit is at the D.C. potential of the cathode of the oscillator tube. The flip-flop is triggered by negative pulses on the grids. It is essential to have the "electron-coupled" flip-flop further insulated from the oscillator by means of cathode-followers and a decoupling *R–C* link. Otherwise disturbances caused by R.F. discharges in the cyclotron tank may easily cause the flip-flop to trigger at an improper time.

An alternative to the electronic pulser is the relay pulser (diagr. *A0, H1, A11, A12*). In this case a flip-flop *A11V6* simulates the action of *H1V2–V3*. The relay *A16K1*, in *A11V6* anode, operates the main control relay $H1K_c$. With this in the closed condition, a negative voltage is applied to the grid of the oscillator tube, thus stopping oscillations. A manual control makes it possible to keep the oscillator running, if desired.

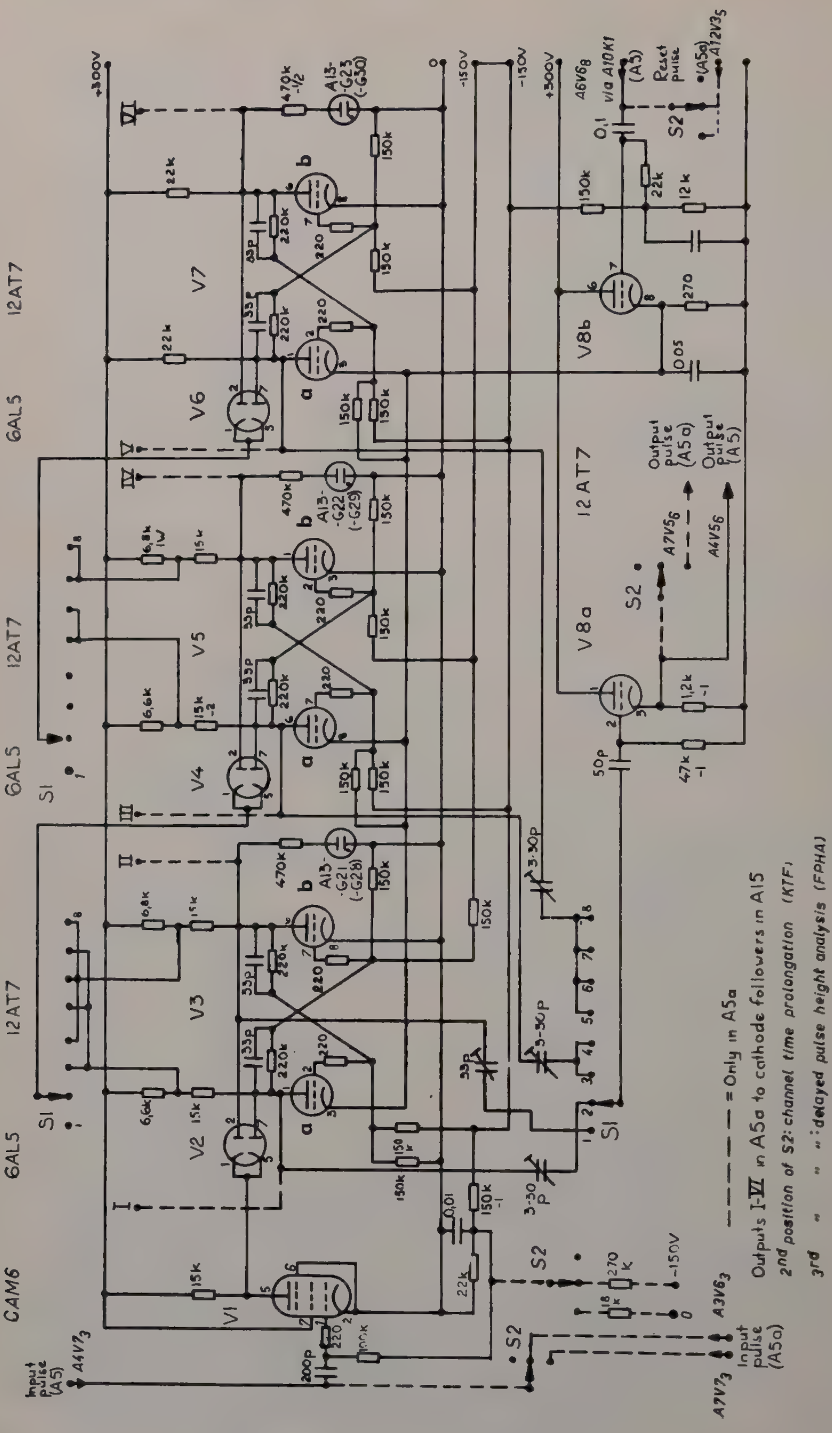
The R_+ pulses also pass through the gate to subunit *A5* which is a pulse counter consisting of three flip-flops which can be arranged to deliver an output pulse after 1, 2, 3, 4, 5, 6, 7, or 8 incoming pulses by suitable arrangement of the coupling between the units and the place for the output. When this preset number of R_+ pulses has been received, an outgoing pulse goes to a coincidence tube *A4V5* where it is mixed with the R_- pulses. (An accidental output pulse from the counter *A5* appearing when it is reset does not produce any coincidence output of *A4V5* because the resetting is done by the *S* pulses at a later time.) *A4V5* works on essentially the same principles as the *A4V4* gate tube. The coincidence output triggers a delay univibrator *A4V10*, which delivers a pulse whose length is variable from a small value to 150 milliseconds. The leading edge of this triggers *A12* which gives a large shut-off pulse to the cyclotron. The trailing edge triggers another univibrator *A4V6* having a pulse length variable up to 150 milliseconds. The leading edge of this pulse closes the gate *A4V4* via *A4V2*. Up to this time all *R* pulses have passed to *A11*. Actually the first *R* pulse passing through triggers the oscillator into oscillation, but the heavy discharges that may happen in the cyclotron tank when switching on the oscillator after an idle period may cause the oscillator to fall out of oscillation if the vacuum conditions are bad. In this case the next *R* pulse triggers it again.

The leading edge of the *A4V6* pulse which appears before the *S* pulse also triggers a flip-flop *A3V3* in subunit *A3* into a definite position. This flip-flop is also continuously triggered back and forth by the *S* pulses, and the rising waveforms at its anodes are taken to a pair of cathode followers *A3V6a* and *A3V6b* through small differentiating capacitors. When the flip-flop is triggered into one of its positions, one of the cathode followers gives a short positive output pulse. When it is triggered back, the other cathode-follower gives a positive pulse.

The output of one of these cathode-followers, *A3V6b*, is taken in coincidence with a negative output from *A4V6*, obtained via cathode-follower *A4V9a*. The *A4V6* pulse is long enough to extend beyond the *S* pulse. The coincidence output opens the gate for channel 1, which thus happens a little after the oscillator is shut off, permitting safe decay of the oscillations before the counting is started. The gate for channel 1 consists of a flip-flop tube *AG1V1* which controls gate tube *AG1V4*. In the "open"



Diagr. *H1*. Cyclotron pulser.



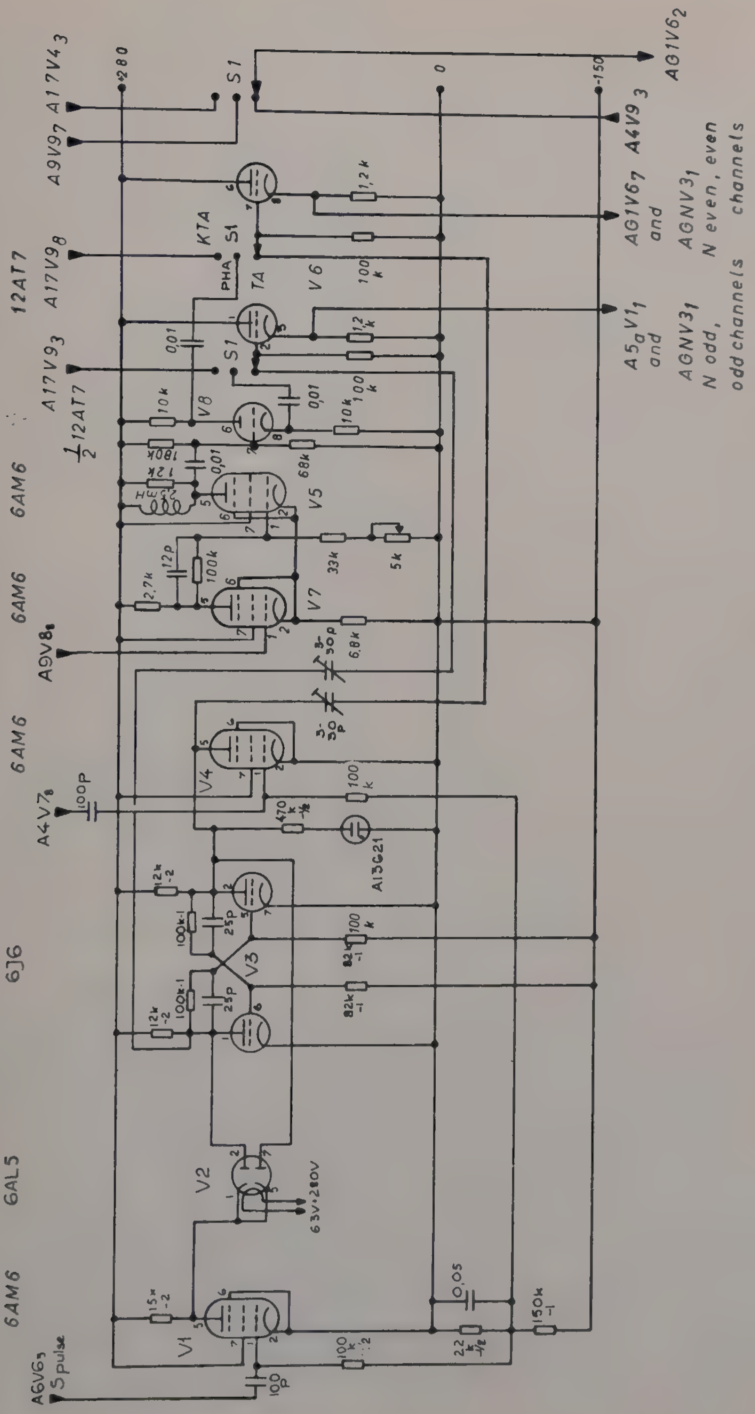
- - - - = Only in A5a

Outputs I-VI in A5a to cathode followers in A15

2nd position of S2: channel time prolongation (KTF)

3rd " " : delayed pulse height analysis (FPHA)

Diagr. *A5–A5a.* Pulse counter.



Diagr. A3. Unit for shut-off pulses to the channel gates.

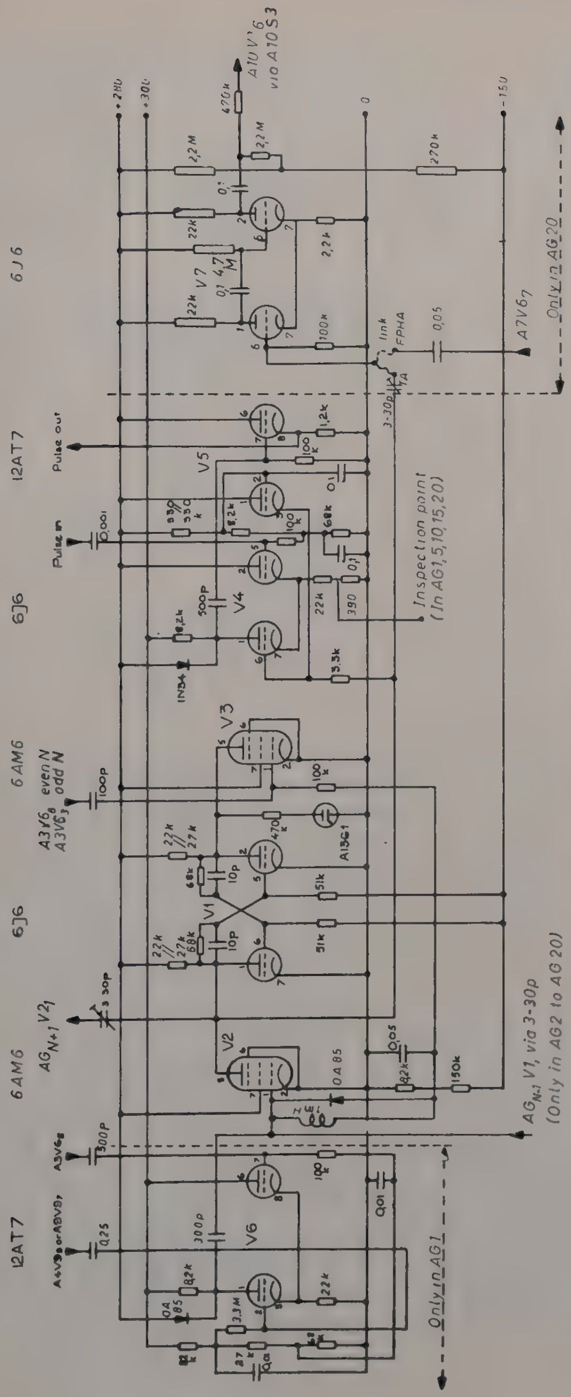
state of the flip-flop, incoming pulses, which are fed to *AG1V4b*, shut off the current in *AG1V4a* and a positive 20 V pulse is fed via cathode-follower *AG1V5b* to the channel memory, which consists of a number of scale-of-ten circuits in series. No output pulse is produced when *AG1V1* switches over, as *AG1V4* conducts enough current even when *AG1V1a* plate is down, to prevent the plate of *AG1V4a* from rising above 280 V. *AG1V5a* functions as a grid-catching cathode follower if the switching action should take the plate of *AG1V1a* to far down. The 3.3 KΩ resistor helps in this function as well as in preventing the $V4_6$ falling waveform from being faster than the time constant, from parasitic capacitance, in the cathode of *V4*. Otherwise a current shift between the halves of *V4* could be caused. The "peaking coil", with its damping diode, in the grid lead of *V2*, speeds up the switching in *V1*. The gate design chosen has the advantage of giving output pulses of the same polarity as the input pulses and having a uniform size as soon as the input pulse has sufficient amplitude to switch the current between the halves of the gate tube.

When *A3V3* is triggered back again by the next *S* pulse the output of the other cathode-follower *A3V6a* shuts off the gate for channel 1 through trigger tube *AG1V3* acting on the flip-flop tube *AG1V1*. At the switching moment this gives a pulse to *AG2V2* via a small capacitor, thus triggering flip-flop *AG2V1*, which controls the channel 2 gate, into the open position.

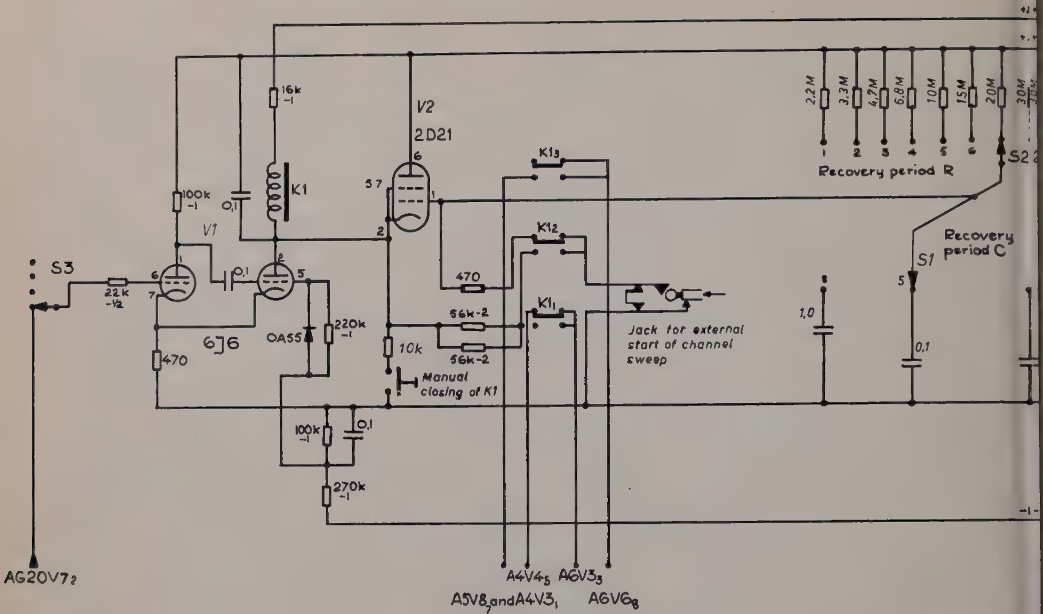
Somewhat later, channel 2 is closed by the pulses from the first cathode follower *A3V6b* acting on flip-flop tube *AG2V1* via trigger tube *AG2V3*. At the same time channel 3 is opened. In this manner each channel is opened by the action of the preceding channel when this is closed. All channels with odd numbers are shut off by the *A3V6a* pulses, those with even numbers by the *A3V6b* pulses. When the 20th channel is shut, the univibrator *AG20V7* is triggered, starting a pulse, which at its end produces a heavy pulse in *A10V1b* and thus closes relay *A10K1* in the sub-chassis for control of the recovery period. When the relay has been closed, the *S* pulses pass through its contacts and reset the pulse counter *A5*. Flip-flop tube *A4V2* is also reset and gate *A4V4* opens. The relay is parallelled by a small thyratron tube with its grid negative. On closing the relay, the grid is left free to raise its potential according to the time constant of an *R–C* combination. This determines the length of the recovery period, which can be up to several minutes long. When the grid has risen sufficiently, the thyratron fires and the relay is released. This starts a new period of bombardment as previously outlined.

When the channels are open, the pulses from the detector pass to the channel scalers, and the decay of a target activity induced during the bombardment can be followed. Interchangeable scalers with different resolution are available and in each channel up to four decade scalers can be used in series, followed by a mechanical register. The resolution of the fastest scaler (diagr. *D1*) is less than 2 μsec. The slow scaler shown in diagr. *D3* has a resolution of ca 35 μsec. and the fast mechanical register shown in diagr. *D4* makes maximum 45 pulses per second.

The detector is a photomultiplier (diagr. *H2*). This is made insensitive during the irradiation by applying a negative voltage to the first dynode. The gating voltage is taken from *A4V2* via cathode-follower *A3V8*, and thus the detector is sensitive only during the counting time for the channels. This prevents overloading of the amplifier for the detector pulses. Overloading can otherwise be caused by a burst of scattered particles hitting the detector crystal during the bombardment or by high frequency pick-up in the detector leads. The presence of the *A4V10* delay ensures that the oscillator is safely shut off before the photomultiplier is made sensitive.



Diagr. *AG1–20.* Gate for the channels.

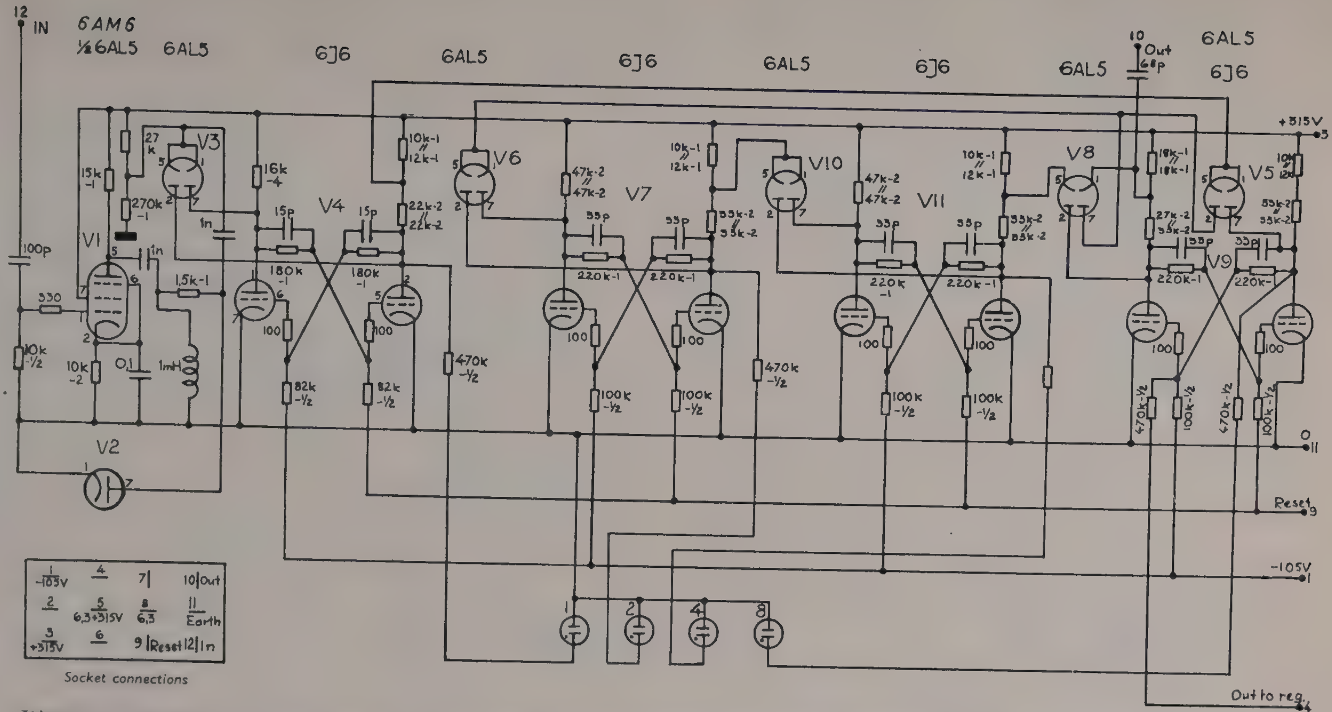


Diagr. *A10*. Control of recovery period.

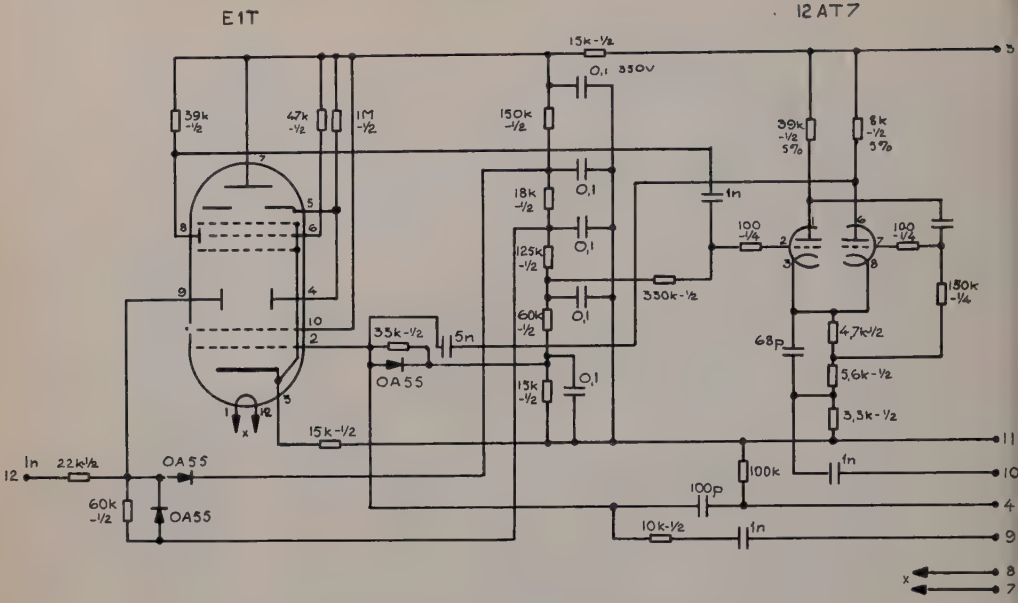
The time needed for shut-off, measured from the action pulse is at most 1 millisecond for the electronic pulser and 30 milliseconds for the relay pulser. The *A4V6* delay ensures that the photomultiplier voltages are in equilibrium before counting is started. The fast coincidence circuit shown in Diagr. *H2* is of the type described by Bell [4] and is used in experiments with two detectors.

In the previous discussion it is assumed that all channels are open equally long times. However, provision has been made for increasing the open time of the late channels 2, 4, or 8 times. This is done by a second pulse counter, subunit 5*a*, almost identical to subunit 5. Pulses from *A3V6a* triggers the first flip-flop tube in 5*a* back and forth. This then triggers the second flip-flop at half the rate of the first. The third one is triggered by the second at half the rate of the second. Pulses are taken at the switching instants from the anodes of the flip-flops to six cathode-followers and the outputs of these can be fed to the switch-off tubes *AGNV3* for any desired channels. In this way one can e.g. arrange the number 6 to 10 channels to be open twice as long time as the first five ones, and the next 5 channels four times as long, and the last 5 channels 8 times as long (Fig. 4).

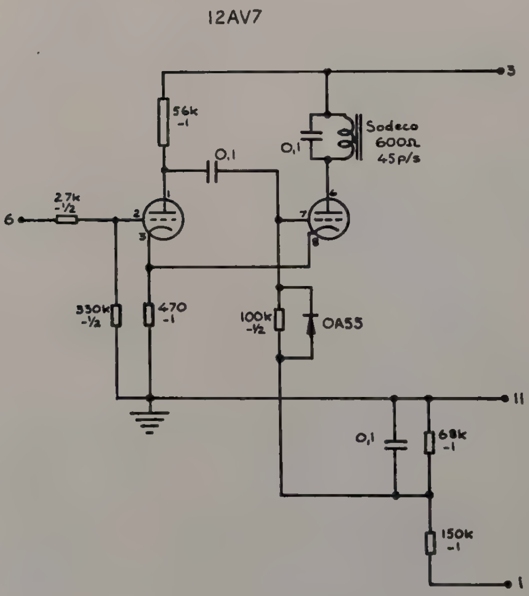
The jack in *A10* for external start of the channel sweep has been used in another application of the instrument, namely for study of short-lived nuclei obtained by milking procedures from longer-lived parents [5]. In this case the thyratron is removed. With proper setting of *A5S1*, the channel sweep is started by the first control pulse appearing after a short-circuit between two leads to the plug in the jack has been removed.



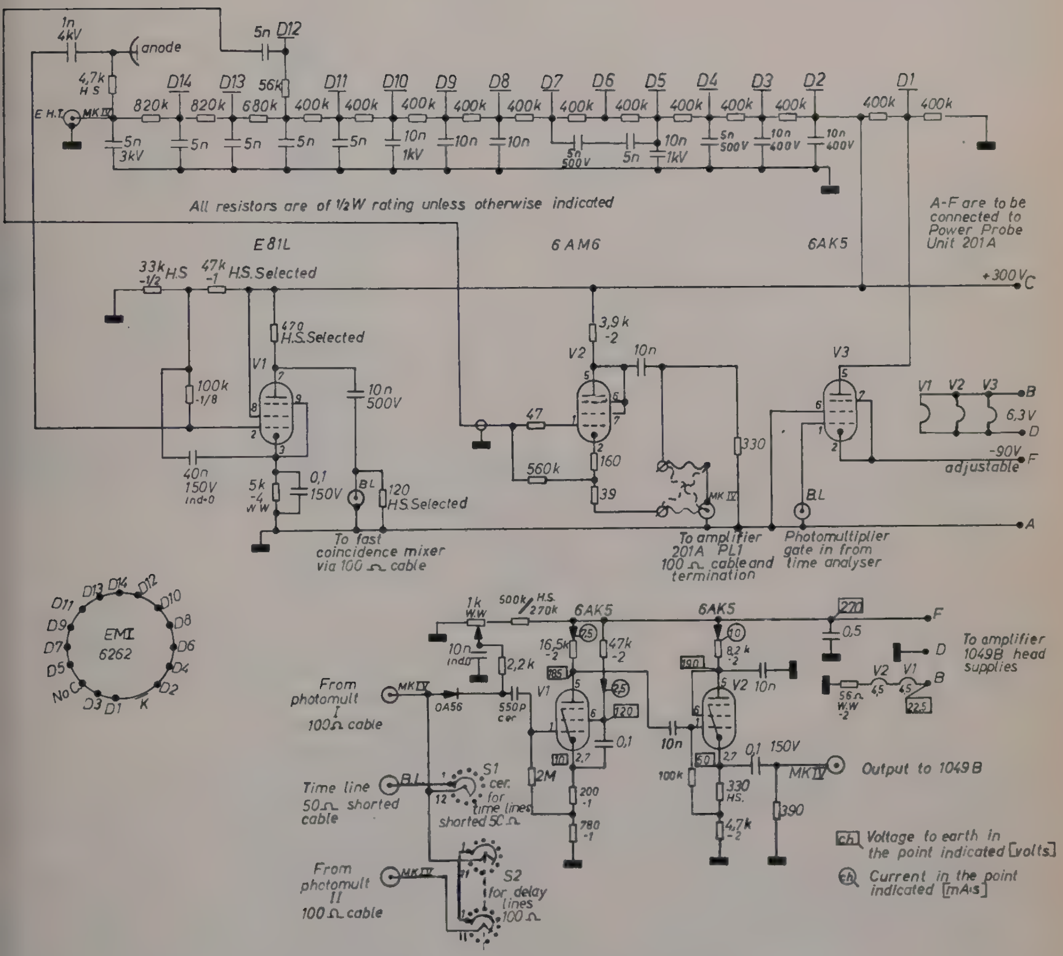
Diagr. *D1.* Fast input decade scaler. The scaling units are plugged into sockets. Sockets in a vertical column (fig. 1) have interconnections in order to accept a chosen number of decade scalers in series. The interconnections are: Pin 10 of lower socket to pin 12 of next higher socket, for feeding an electronic decade, and pin 4 at lower socket to pin 6 of next higher, for feeding a mechanical register. The reset lead is normally connected to −105 V, but receives a positiv pulse at the moment of resetting. The scalers are fed from a power supply similar to that used for the analyser.



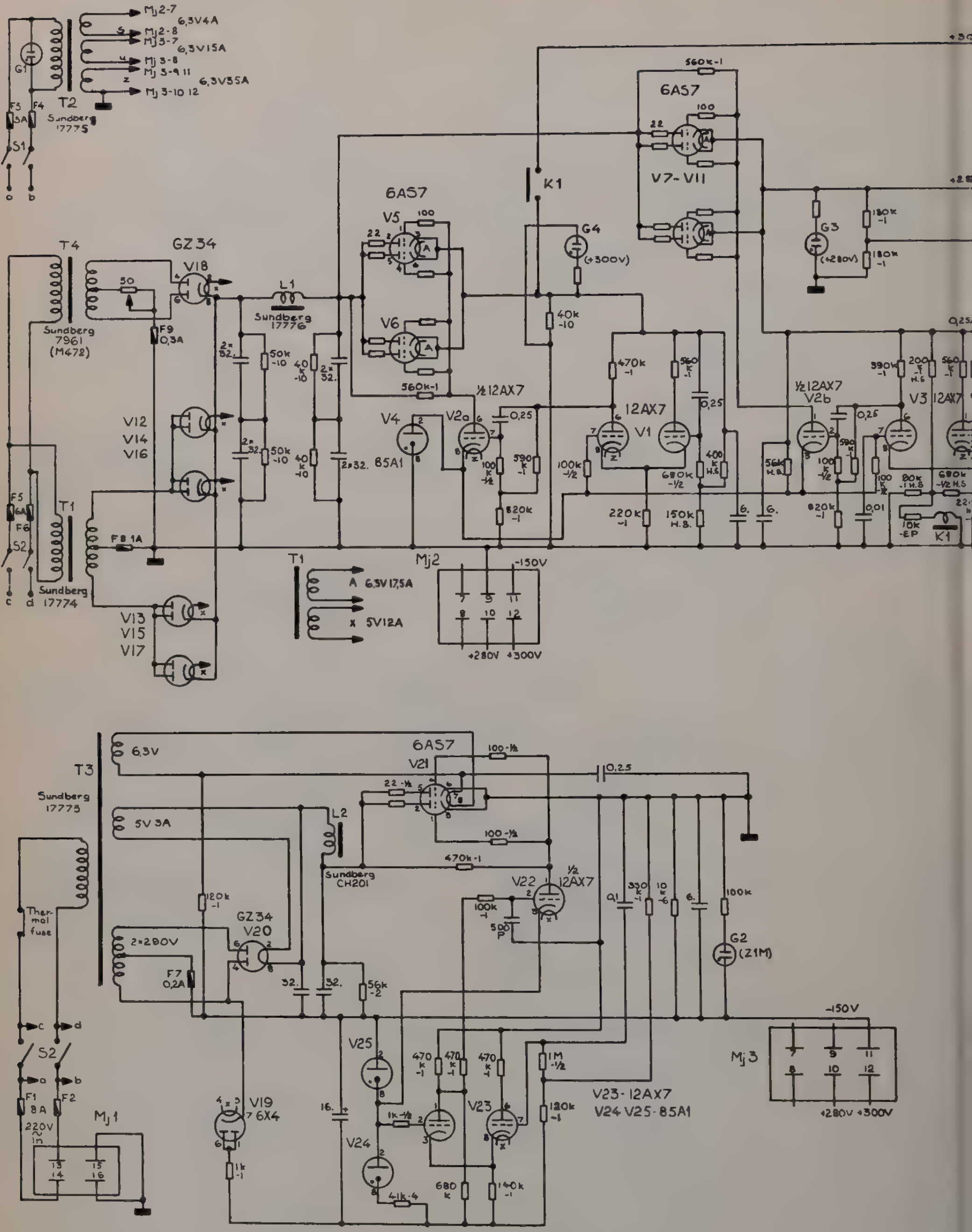
Diagr. *D3*. Slow decade scaler.



Diagr. *D4*. Fast register.



Diagr. *H2*. Photomultiplier unit with fast coincidence mixer.



Diagr. *M*. Power supply for analyser.

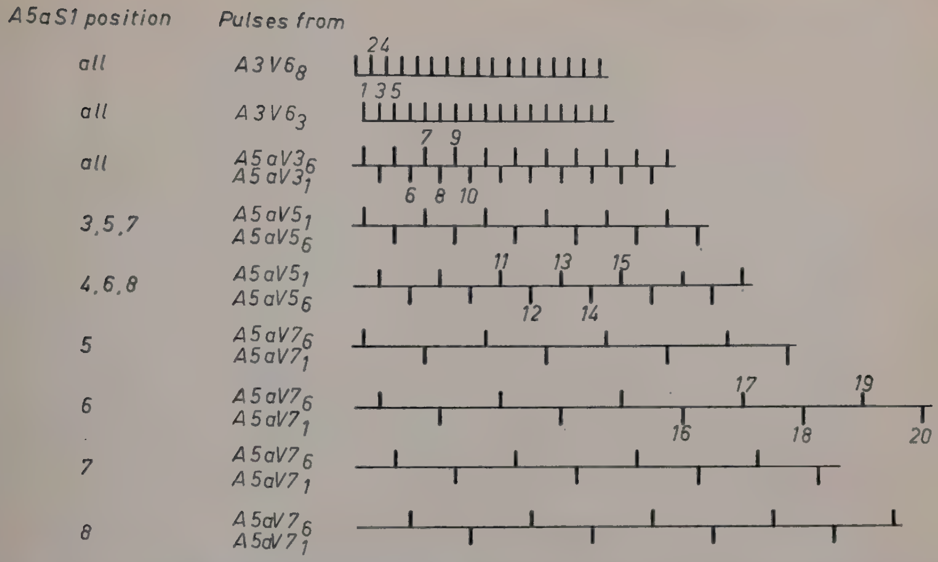


Fig. 4. Shut-off pulses obtainable from *A5a* when used for channel time prolongation (*KTF*). The pulses chosen for different channels are marked out for the case that the channel time is doubled every fifth channel.

2. *Application for measurements on isomeric states*

This has been described elsewhere [3]. A subunit, *A17*, described in ref. [3], is used to carry through a rapid sequence of opening and closing of the channels for this kind of operation, named *KTA* in diagram *A0*.

3. *Pulse-height analyser function*

The time analyser can be rearranged to function as a 20-channel pulse-height analyser. This is described mainly in Diagr. *A0*, *A8* and *A9* and Fig. 5.

The pulse, whose height is to be analysed, starts a pulse train which causes the 20 channels to open and shut successively as described for the time analyser function. The open time of each channel can be set to 14 or 2 microseconds. Another pulse generator, which is also triggered by the incoming pulse, gives a rectangular pulse, whose length is proportional to the height of the incoming pulse. This rectangular pulse is differentiated, and the trailing edge of it passes into the channel which is open at that time.

The pulse train generator constitutes subunit *A9*. The incoming pulse triggers the Schmitt discriminator *A9V1* and *A9V2*. The discriminator output pulse triggers the delay univibrator *A9V4* via trigger tube *A9V3*. This can be gated on its suppressor grid, and by shutting off *V10*, in its cathode lead, if the incoming pulse is not desired. At the end of the *A9V4* delay period which is made somewhat longer than the rise time of the incoming pulse, another delay univibrator *A9V5* is triggered. A waveform from this shuts off *V10*. At the end of *V5*'s delay period, which is several microseconds long, the univibrator *A9V6* is triggered. As soon as this happens, trigger tube *A9V3* is cut off on its suppressor grid, thus preventing any further incoming pulses from triggering *A9V5* (and hence *A8V9–V10*).

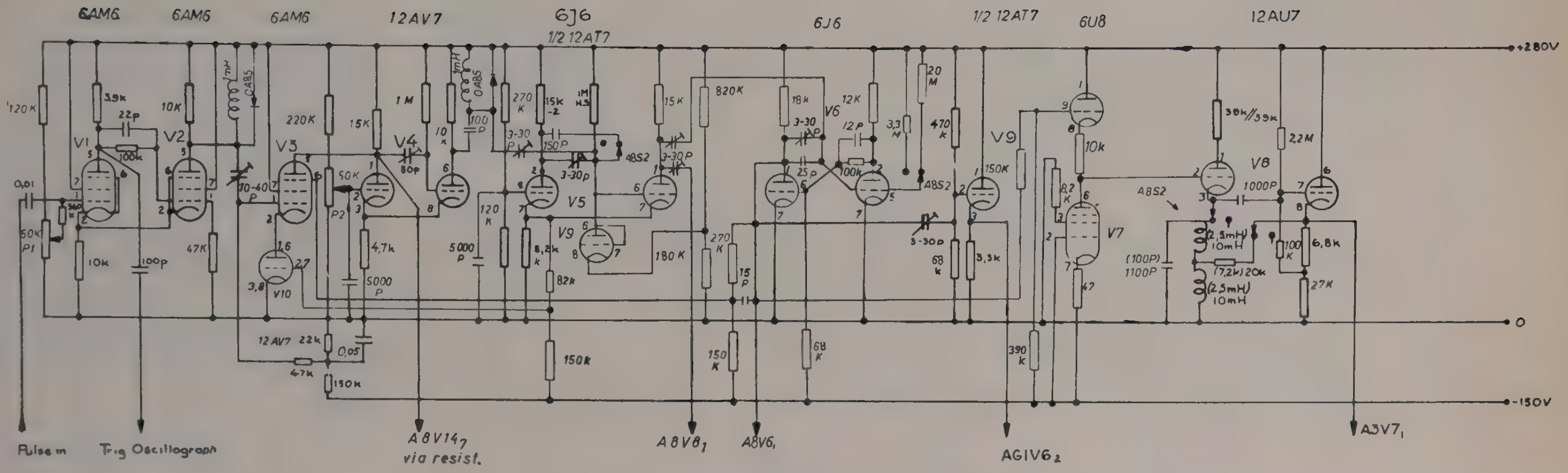
The large voltage change at *A9V6a* anode is transferred to the grid of *A9V8* via *V7* which shifts the D.C. level, while maintaining the largest part of the amplitude and the D.C. coupling that is used in the interstage couplings when long pulses are concerned. This is desirable when high duty cycle ratios are used in the pulse generators. The current through *V7* is practically constant and determined by the pentode part which is coupled as a constant-current device. *A9V8* is a pulsed L.C. oscillator with positive feedback to maintain constant oscillation amplitude. When the current in *A9V8a* is shut off, the ringing circuit in the cathode gives a sine wave train which lasts as long as the negative pulse on *A9V8a* grid. The sine wave is shaped into two trains of short pulses with the pulses of the second train placed midway between those of the first train. This is done in *A3V5* and *A3V7*. The sine wave on the grid of *A3V5* switches the current between the two valves. The switching occurs very near the zeros of the sine wave, and the wavefronts at the anode of *V5* are shaped to short pulses by the 2.5 mH inductance. After separation of positive and negative pulses in *V8* these are taken to open and shut the 20 channels in rapid sequence as outlined for the time analyser function. The coincident pulse which is needed for opening the first channel at the start of the pulse train is taken from the plate of *A9V6*.

The translation of pulse height into pulse length is done in subunit *A8*. The incoming pulses are fed to a difference amplifier with negative feed back, consisting of *A8V1* and *A8V2*. The amplifier can be set to choose a definite height interval among incoming pulses. The position and the width of the interval can be varied, the the former by potentiometer *A8P1* and the latter by switch *A8S1*, which alters the amplification of the difference amplifier by altering the negative feedback. The widths that can be chosen are 5, 10, 20 and 40 V for coverage of the 20 channels. The back-bias on *V1* grid can be varied up to −100 V by adjusting *P1*. An output pulse is taken from *A8V2* anode to the cathode-follower *A8V4*, which charges a 270pF condenser *A8C1* through diode *A8V5a*. The voltage increase across *A8C1* is linearly related to the height of the incoming pulse and is applied to the grid of *A8V9*.

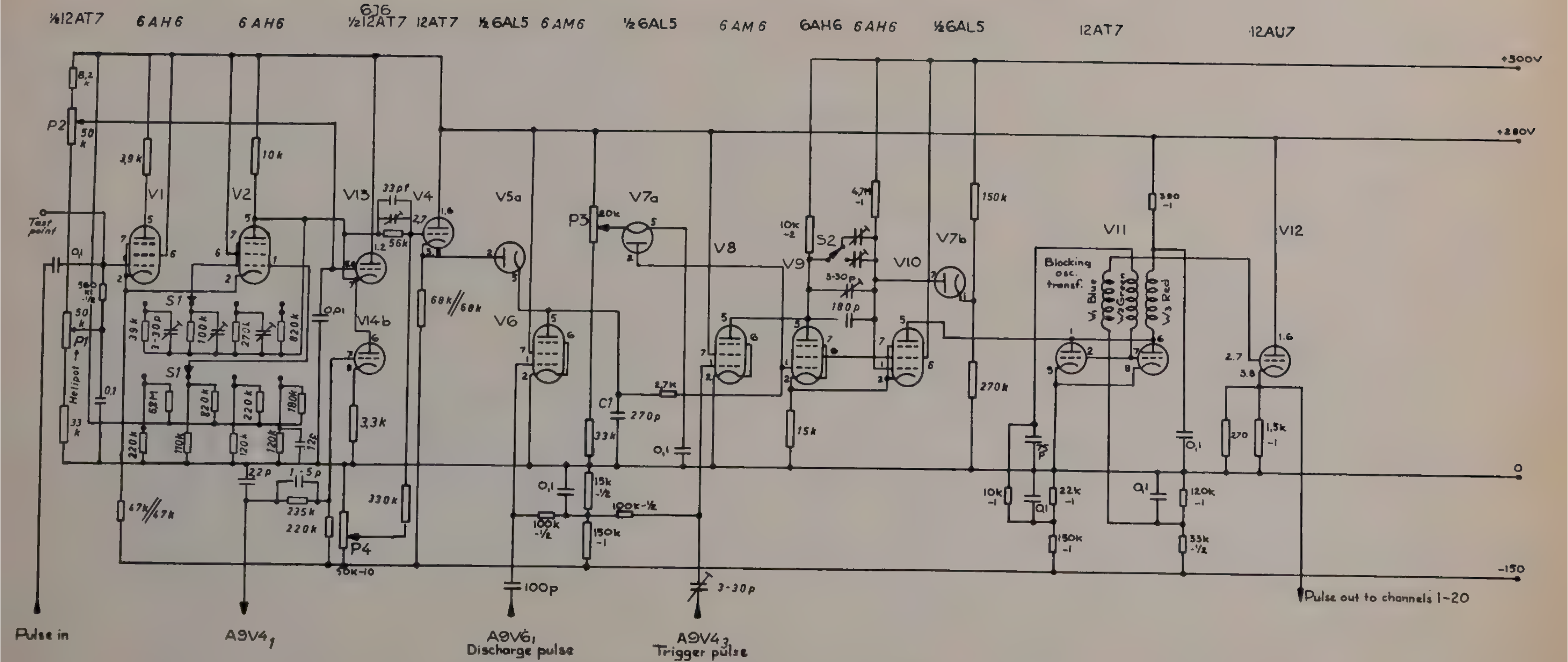
A8V9 and *A8V10* constitute a cathode-coupled univibrator, whose pulse length is linearly related to the potential at *A8V9* grid. (For a discussion of the linearity see ref. [6].) This univibrator is triggered at the end of the *A9V4* delay period by trigger tube *A8V8*. One purpose of the delay univibrator *A9V5*, which somewhat later triggers the pulse train for the channel sweep, is to avoid using the very first part of the pulse height to time translation characteristics of *A8V9–V10*. Another purpose is to give recovery time for the univibrators *A8V9–V10* and *A9V6*. A new triggering of these immediately after their pulse is finished could give differing pulse length. The *A9V4* delay permits setting the analyser for different rise times, and it is chosen to be slightly longer than the rise time. The anode load of *A8V10* is common to *A8V11*, which is a blocking oscillator. This is triggered at the end of the *A8V10* pulse when the anode is going negative. The short output pulse of *A8V11*, 0.1–0.2 microsecond long, is passed to all 20 channels.

The grid-catching diode *A8V7b* provides good stability in the pulse length of the univibrator *A8V9–V10* by keeping the grid at a constant potential. The same coupling is used in *A9V5*.

A8V13 and *A8V14b* prevent pulses which arrive during the dead time of the analyser, that is every time except during the pulse of *V4*, from affecting the measurement of the accepted pulse. This is done by causing *A8V14b* to draw current through



Diagr. *A9.* Pulse train generator for channel sweep.



Diagr. *A8*. Unit for translation of pulse height into pulse length.

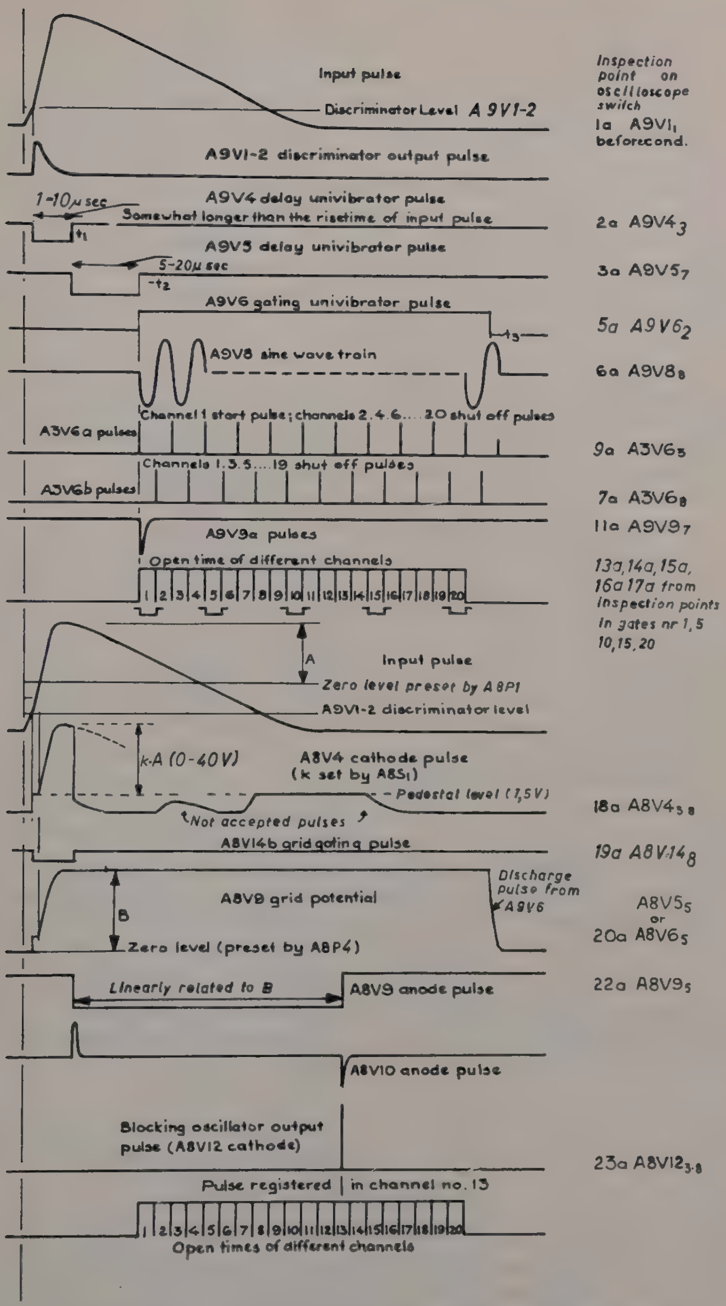

Input pulse
Discriminator Level A 9V1-2
Inspection point on oscilloscope switch
1a A9V1₁ beforecond.
A9V1-2 discriminator output pulse
1-10μ sec
A9V4 delay univibrator pulse
Somewhat longer than the risetime of input pulse
t₁
2a A9V4₃
A9V5 delay univibrator pulse
5-20μ sec
t₂
3a A9V5₇
A9V6 gating univibrator pulse
t₃
5a A9V6₂
A9V8 sine wave train
6a A9V8₈
Channel 1 start pulse; channels 2.4.6.... 20 shut off pulses
A3V6a pulses
9a A3V6₅
Channels 1.3.5....19 shut off pulses
A3V6b pulses
7a A3V6₈
A9V9a pulses
11a A9V9₇
Open time of different channels
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
13a, 14a, 15a, 16a 17a from inspection points in gates nr 1, 5 10, 15, 20
A
Input pulse
Zero level preset by A8P1
A9V1-2 discriminator level
k·A (0-40 V)
A8V4 cathode pulse (k set by A8S₁)
Pedestal level (1,5 V)
18a A8V4₃ ₈
Not accepted pulses
A8V14b grid gating pulse
19a A8V14₈
Discharge pulse from A9V6
A8V9 grid potential
B
Zero level (preset by A8P4)
A8V5₅ or
20a A8V6₅
Linearly related to B
A8V9 anode pulse
22a A8V9₅
A8V10 anode pulse
Blocking oscillator output pulse (A8V12 cathode)
23a A8V12₃.₈
Pulse registered | in channel no. 13
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Open times of different channels

Fig. 5. Waveforms observable in pulse-height analyser function.

A8V13 and the anode load of *A8V2*. With *V14* removed, and *V2* taking all the current in the difference amplifier, the grid potential of *V13* is adjusted to the point where *V13* is just barely cut-off, as measured by a voltmeter at the anode of *V2*. Then with *V14* in place, the current in this tube is adjusted, by altering the cathode resistor, to be slightly more than the current drawn by *V2*. The potential of *V2* anode then drops a small amount (the pedestal level in Fig. 5) so that *V13* takes the current in *V14*. When *V14* is cut off by a negative pulse from *A9V4*, the *V2* anode potential is first able to rise and reproduce a simultaneous pulse at the grid of *V1*.

Normally the inputs of *A8* and *A9* are coupled together but if desired, as in coincidence experiments, separate inputs are used. Then the pulses to be measured are applied to *A8* while the output from the coincidence circuit is applied to *A9*. The resolution obtained, as far as concerns measuring pulses, is the same as the pulse length of *A9V4*.

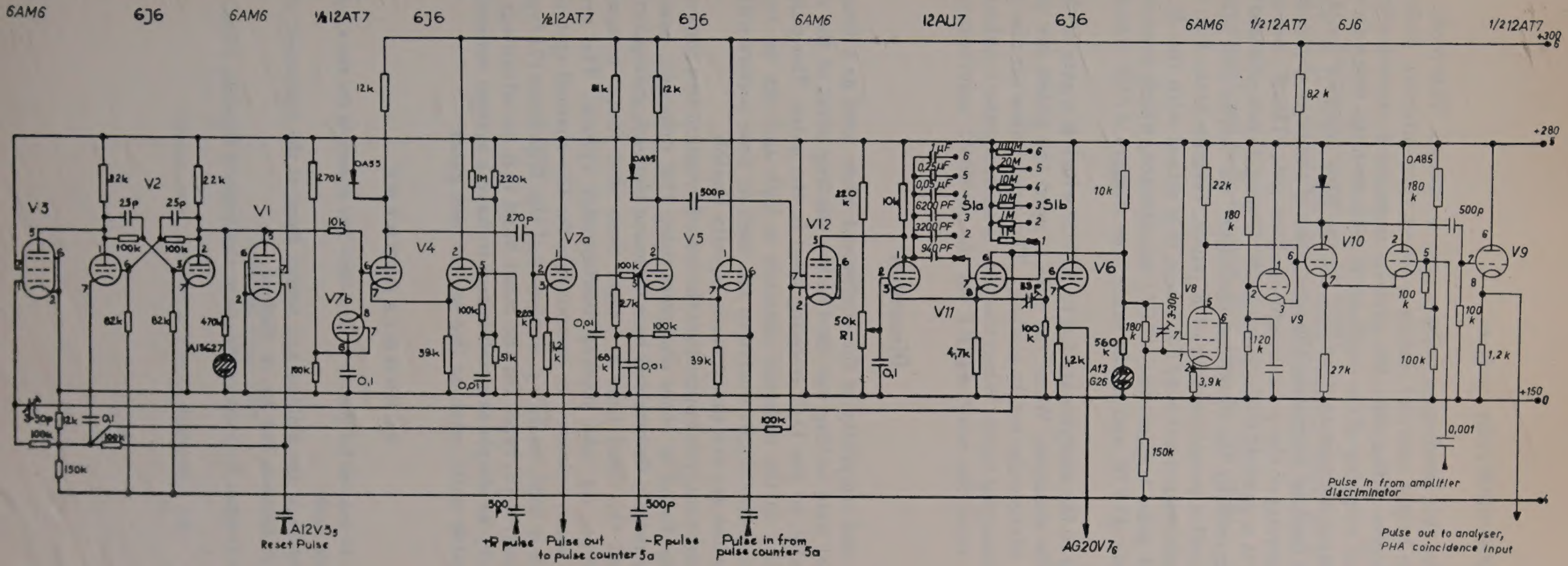
Adjustment on potentiometer *P4* selects the zero level for the grid voltage of *A8V9*. The diode *A8V7a* prevents the *A8V9* grid potential from rising above the level set by *P3*. This can be adjusted to cause all input pulses above the level of the 19th channel to be registered in channel 20. The pentode *A8V6* discharges condenser *A8C1* quickly at the end of the *A9V6* gating pulse and the discharge pulse is sufficiently large to draw some current also through *V4*. The zero level is then determined by *V4*. Shortly afterwards the analyser is ready to register another input pulse.

To avoid base-line shifts at high pulse rates the difference amplifier and subsequent circuits in *A8* are D.C.-coupled. The D.C. interstage couplings in *A9* and *A3* also makes pulse lengths, positions and amplitudes independent of the pulse rate. The D.C.-coupling used in *A8* also make it possible to check the analyser by applying a D.C. voltage, which can be accurately measured, to the grid of *V1*. The analyser is then triggered by pulses and the channel position is noted as a function of input voltage. The long scale of *A8P1* is calibrated in volts for every setting of *A8S1*.

The circuits can thus be arranged to function as a 20-channel pulse height analyser with a resolution time of a few microseconds, a dead time of approximately 50 or 300 microseconds, and suitable for pulses from 5 to 45 V or for smaller bands 20, 10, or 5 V wide, in the 5–100 V range. The design is intended for analysis of pulses from amplifiers having rather small saturation voltages of 40–50 V. The dead time is the same for all pulse-heights, but arrangements could be made to shut off the channel sweep after the pulse has been registered. This would approximately halve the mean dead time. The larger t_k and hence longer dead time is normally used as it yields a better equality of channel widths. The error in this is less than 2 %. This is determined by triggering *A9* and *A8V9–10* by two unrelated sets of randomly distributed pulses, and comparing the counts in the channels.

4. *Pulse height analyser function during a chosen time interval after a cyclotron bombardment*

This mode of operation can be used when it is desired to measure the pulse-height spectra from short-lived nuclei. By displacing the sensitive time interval the decay of the peaks can be followed, and determination of the part of the spectra that is due to the background can be made. The function is described in diagr. *A0* and is there called "*FPHA* function". In this mode of operation the oscillator of the cyclotron is switched on for a short period, allowing bombardment of a target. At



Diagr. *A7.* Gate unit for *FPHA* function.

a chosen time after this irradiation pulse a gate is opened. This feeds the detector pulses to the pulse-height analyser during a preset time interval. Following this, a recovery period begins. After this, the cycle is repeated automatically.

The starting and stopping of the oscillator is done with the help of a control pulse generator in the same manner as described for the time analyser function. Subunit 5*a* which was then used for increasing the open time of the later channels is now used for delaying the opening of the pulse-height analyser gate. The R_+ pulses trigger the pulse counter 5*a* via a gate *A7V4* in subunit *A7*. This gate is controlled by a flip-flop *A7V2*. This is triggered by the cyclotron oscillator "off" pulse and opens the gate. When 5*a* has counted a preset number of R pulses, variable from 1 to 8, an output pulse is fed to a coincidence tube *A7V5*, where it is mixed with the R_- pulses. The coincidence output pulse triggers the *A7V11* univibrator, which controls the pulse-height analyser gate *A7V10*, and at the same time triggers *A7V2*, which then closes the *A7V4* gate.

The input pulses to the analyser are fed to *A7V10* which is a gate of the same type as those used in the channels. When the gate is open the pulses are passed to the coincidence input of the pulse-height analyser. The input pulses are also permanently fed to the pulse measuring input. When the gate is shut, a pulse is taken via cathode follower *A7V6* to close the relay *A10K1* via the *AG20V7* univibrator.

Discussion

The wide range and simplicity of the equipment when used as a time analyser is due to the fact that time sorting was used as the starting point at the construction, and more specifically, to the D.C. coupling used in the gates. The pulse resolution and storing capacity in the different channels is high and can be varied at will. Other designs were pulse-height analysers are used as time sorters with the help of transformation devices are not easily made equally flexible.

For the pulse-height analysis application the transformation to a time measurement gives the advantage found in other analysers using this principle, namely, that the channel widths are mainly determined by a common element, giving better equality. On the other hand the dead time is longer than that found in analysers of the "parallel-input" type, e.g. the stacked-discriminator system. The present design does not offer the same economy in components for the channel system, if a larger number of channels is used, as do e.g. analysers of the Wilkinson [7] type and of the Hutchinson and Scarrot [8] type. On the other hand it is an advantage to have the logics of the circuitry as simple as possible and to have a system consisting of equal, easily interchangeable units, such as the scalers and gates.

ACKNOWLEDGEMENT

The author wants to express his thanks to Professor The Svedberg for the kind way in which he has facilitated this work.

Valuable contributions in the building and testing stage of the equipment were made by Mr. S. Sundell, Mr. P. Isacsson and Mr. A. Östlund.

The Gustaf Werner Institute for Nuclear Chemistry, University of Uppsala, Uppsala, April 1958.

REFERENCES

1. H. Tyrén and P. A. Tove, Phys. Rev. *96*, 773 (1954).
2. P. A. Tove, Arkiv Fysik *13*, 549 (1958).
3. P. A. Tove, Nuclear Instruments *1*, 95 (1957).
4. R. E. Bell, R. L. Graham and H. E. Petch, Canad. J. Phys. *30*, 35 (1952).
5. G. Andersson, P. A. Tove, B. Jung and I. B. Svensson, Nuclear Physics *3*, 493 (1957).
6. K. Glegg, Proc. IRE *38*, 655 (1950).
7. D. H. Wilkinson, Proc. Cambridge Phil. Soc. *46*, 508 (1949).
8. G. W. Hutchinson and G. G. Scarrot, Phil. Mag. *42*, 792 (1951).

Tryckt den 7 maj 1958

Uppsala 1958. Almqvist & Wiksells Boktryckeri AB